

OCCURRENCE OF NITRATE, PESTICIDES, AND VOLATILE ORGANIC COMPOUNDS IN THE KIRKWOOD-COHANSEY AQUIFER SYSTEM, SOUTHERN NEW JERSEY

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ABSTRACT

Water samples were collected from a network of 72 shallow monitoring wells to assess the chemical quality of recently recharged ground water in the surficial Kirkwood-Cohansey aquifer system of southern New Jersey. The wells are randomly distributed among agricultural, urban, and undeveloped areas to provide data representative of chemical conditions of ground water underlying each of these land-use settings. Samples were analyzed for nutrients, pesticides, and volatile organic compounds (VOC's). Concentrations of nitrate were highest in agricultural areas, where the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) of 10 mg/L (milligrams per liter) as nitrogen was exceeded in 60 percent of the samples. Concentrations of nitrate were intermediate in urban areas, where the 10-mg/L concentration was exceeded in only 1 of 44 samples. All concentrations in samples from undeveloped areas were less than 1.0 mg/L. Pesticides and VOC's were frequently detected; however, concentrations were low and rarely exceeded established or proposed USEPA or N.J. Department of Environmental Protection (NJDEP) drinking-water regulations. With the exception of the agricultural pesticide dinoseb, established regulations are at least 2.9 times the maximum concentration for pesticides and at least 5 times the maximum concentration for VOC's reported in the samples from the 72-well network.

Investigations by the U.S. Geological Survey (USGS) are ongoing in southern New Jersey to evaluate the (1) presence and concentration of pesticide-degradation byproducts in shallow ground water; (2) presence and movement of nitrate, pesticides, and VOC's in the atmosphere, streams, unsaturated zone, and aquifers; (3) transport and fate of these compounds as they migrate deeper into the aquifer system; and (4) implications of these findings for the integrity of the regional water supply.

INTRODUCTION

The chemical quality of ground water is a primary concern where ground-water resources are used for public and domestic supply. The chemical quality of ground water is determined by the chemical properties of precipitation, the mineralogy of soils and aquifer materials through which the water moves, and the length of time the water has been in contact with these soil and aquifer materials. The chemical quality of ground water can be altered, however, by the introduction of contaminants into the environment.

Chemicals enter the environment from either point or nonpoint sources. Point sources are discrete sources in which concentrations of contaminants generally are elevated. Examples include outflow from pipes, leaking underground storage tanks, and accidental spills of chemicals. In contrast, nonpoint sources are areally extensive sources of contaminants in which concentrations generally are low. Examples include the widespread application of fertilizers and pesticides in agricultural areas and emissions from automobiles in urban areas.

The chemical quality of ground water is of particular concern in the Glassboro study area in southern New Jersey (fig. 1) because ground water provides most of the public and domestic supply. This is one of the fastest growing regions in New Jersey. Its population was more than 250,000 in 1990 and is expected to increase as suburban development continues (N.J. Department of Environmental Protection, 1993). Residential and commercial developments built within the last 3 decades occupy large tracts of land that previously were undeveloped or used for orchard and row-crop farming.

The NJDEP has identified serious water-supply problems

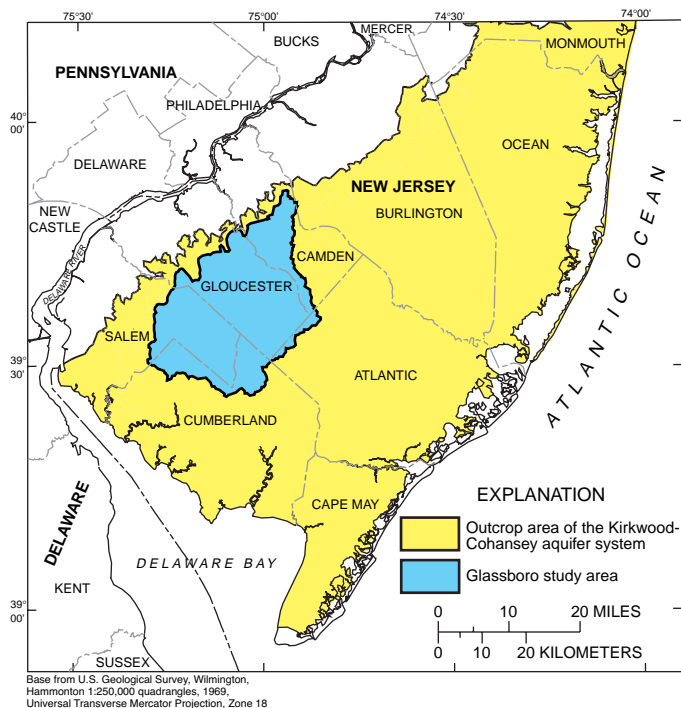


Figure 1. Location of Glassboro, New Jersey, study area.

in the Glassboro study area (N.J. Department of Environmental Protection, 1993). Historically, this region has relied heavily on the confined Potomac-Raritan-Magothy aquifer system for public-water supply. More recently, the NJDEP has restricted withdrawals from this aquifer system as a result of severe water-level declines (N.J. Department of Environmental Protection, 1996a). Increased withdrawals from the surficial Kirkwood-Cohansey aquifer system is one alternative to meet current and future water-supply demands. The aquifer system is vulnerable to contamination introduced at or near land surface because it consists of highly permeable unconsolidated sands and gravels. The chemical quality of water in the Kirkwood-Cohansey aquifer system is of concern because of the increasing reliance on this aquifer system for public and domestic supply.

A network of 72 shallow monitoring wells (fig. 2), installed as part of the USGS's National Water-Quality Assessment (NAWQA) program, provides an opportunity to assess the chemical quality of water in the surficial aquifer system within the 380-square-mile Glassboro study area. The NAWQA program is designed to (1) provide a consistent description of current water-quality conditions for a large part of

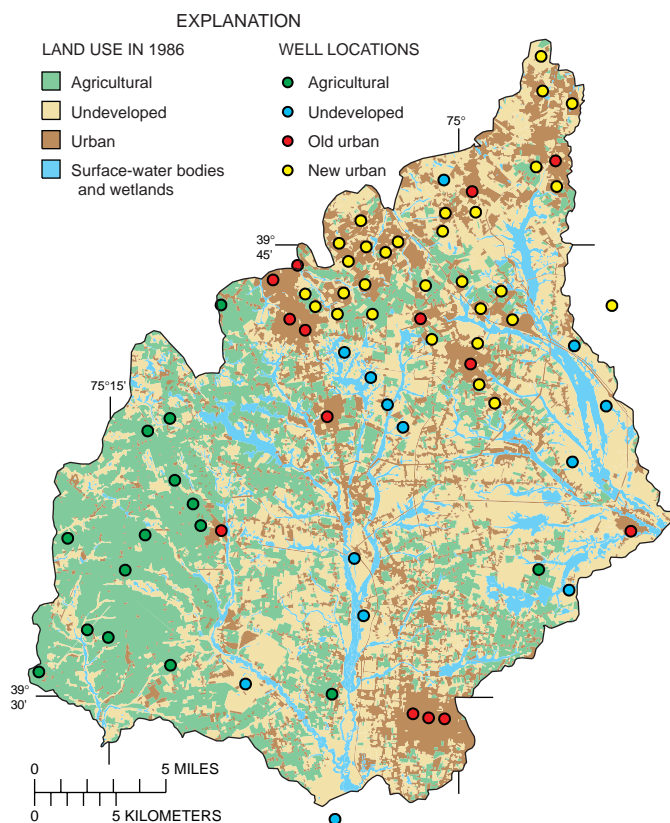


Figure 2. Land use and well locations in the Glassboro study area, New Jersey. (Land-use data from N.J. Department of Environmental Protection, 1996b)

the Nation's water resources; (2) define any long-term trends in water quality; and (3) identify, describe, and explain, to the extent possible, the major natural and human factors that affect observed water-quality conditions and trends (Leahy and others, 1990).

This monitoring-well network was designed to provide chemical data representative of the quality of recently recharged

ground water in each of the major land-use settings in the Glassboro study area. Recently recharged ground water is shallow and, therefore, more vulnerable to contamination than older (deeper) ground water. As of 1986, the primary land-use classifications in the study area were agricultural (26 percent), urban (21 percent), and undeveloped (39 percent). Surface-water bodies, wetlands, and other miscellaneous land-use categories make up the remaining 14 percent of the study area (N.J. Department of Environmental Protection, 1996b). For this study, the urban category is subdivided into areas of residential and commercial development less than 30 years old (new urban) and those more than 30 years old (old urban). Well locations in each land-use setting were randomly selected with a grid-based random site-selection program (Scott, 1990) to ensure that water-quality data collected from the network are unbiased and representative of the quality of recently recharged ground water across the region. Prior to well installation, it was confirmed that at least 75 percent of a 500-meter-radius zone surrounding each well location consisted of the target land use (for example, agricultural) to further ensure that water-quality data collected from the network would be representative of chemical conditions of ground water underlying each of the land-use settings. Wells were installed as follows: 15 in agricultural areas, 13 in undeveloped areas, 14 in old urban areas, and 30 in new urban areas (fig. 2). Each well is constructed with 2-inch-diameter threaded polyvinyl chloride pipe and typically is screened over a 2-foot interval about 10 feet below the water table. Because well sites in the study area that met all the aforementioned criteria for well-site selection were sometimes difficult to locate, two wells were installed outside the study-area boundary (fig. 2). These two sites also met all the well-site-selection criteria. Wells were installed and sampled according to protocols and procedures described in Lapham and others (1995) and Koterba and others (1995). Each well was sampled once during September-December 1996.

Samples from each well were analyzed for nutrients, pesticides, and VOC's. VOC concentrations were determined at the USGS National Water Quality Laboratory by purge-and-trap isolation and concentration, and capillary-column gas chromatography/mass spectrometry methods (Rose and Schroeder, 1995). Pesticide concentrations were determined by either solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected ion monitoring (Zaugg and others, 1995) or solid-phase extraction with high-performance liquid chromatography (Werner and others, 1996). The reporting level for reliable quantitation for VOC's and pesticides is referred to as the nondetect value (NDV). If a VOC or pesticide is confirmed to be present in a sample at a concentration less than the NDV, the concentration is reported as estimated and assigned an "E" prefix (for example, E0.002 $\mu\text{g/L}$ (micrograms per liter)). A quality-assurance program was used in the field (Koterba and others, 1995) and the laboratory (Rose and Schroeder, 1995; Zaugg and others, 1995; Werner and others, 1996) to evaluate and ensure the reliability of the analytical results.

This report summarizes water-quality data from the 72-well network in the Glassboro study area. Concentrations and distributions of the most frequently detected nutrients, pesticides, and VOC's in recently recharged ground water underlying the major land-use settings are presented, and

implications for the use of the surficial Kirkwood-Cohansey aquifer system as a source of public and domestic supply are discussed.

NITRATE IN RECENTLY RECHARGED GROUND WATER

Nitrate, a stable species of nitrogen in oxygenated subsurface environments, was the most frequently detected nutrient in recently recharged ground water from the Glassboro study area. Concentrations of other nitrogen species, such as nitrite, were negligible (generally less than 0.02 mg/L) and are not discussed further in this report.

Natural sources of nitrogen, such as precipitation and plant residues, generally contribute low concentrations of nitrate to ground water. Inputs from human sources, such as domestic and agricultural fertilizers and effluent from leaking sewer lines, cesspools, and septic tanks, can increase nitrate concentrations significantly in recently recharged ground water beneath agricultural and urban areas. High concentrations of nitrate in ground water can pose a serious health threat, especially to infants and farm animals whose digestive systems convert nitrate to nitrite, which reduces the oxygen-carrying capacity of blood and results in the disease methemoglobinemia ("blue-baby syndrome"). The USEPA has established a MCL for nitrate of 10 mg/L as nitrogen in water that is delivered to any user of a public water system (U.S. Environmental Protection Agency, 1996).

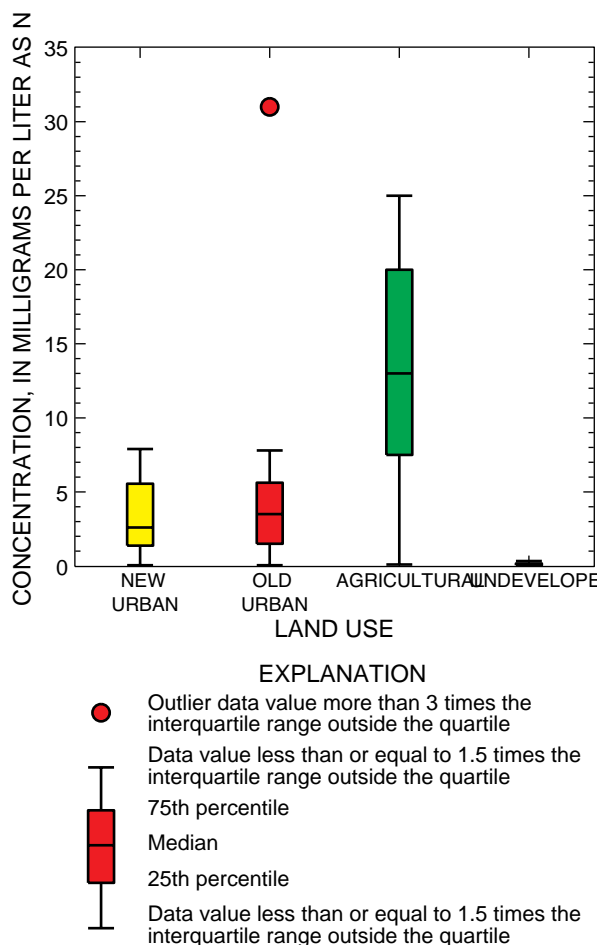


Figure 3. Distribution of nitrate concentrations in ground water by land-use setting, Glassboro study area, New Jersey.

The median concentration of nitrate was highest (13.0 mg/L) in samples from agricultural areas, where nitrogen fertilizers are used for crop production (fig. 3). Nitrate concentrations in 60 percent of the samples from agricultural areas exceeded the 10-mg/L MCL, reflecting both the intensive use of nitrogen fertilizers and manure to support crop production, and the well-drained and aerated soils that favor the formation and leaching of nitrate. Median nitrate concentrations in samples from the new and old urban areas, where nitrogen sources include domestic fertilizers and sewage wastes, were similar (2.6 and 3.5 mg/L, respectively). Only one sample from the new and old urban settings contained nitrate at a concentration that exceeded the 10-mg/L MCL. Nitrate concentrations were lowest (median 0.07 mg/L) in undeveloped areas, reflecting the lack of human inputs of nitrogen into the subsurface environment in these areas.

PESTICIDES IN RECENTLY RECHARGED GROUND WATER

A pesticide is any substance or mixture of substances used to control pests, such as insects, weeds, and fungi. Although synthetic organic pesticides were introduced in the 1940's, reliable records on their manufacture and use were not compiled until the 1960's. Since then, their manufacture and use have increased steadily (Smith and others, 1988; Barbash and Resek, 1996). Pesticides have long been used in agricultural settings; in the last several decades, their use in nonagricultural settings, such as urban and undeveloped areas, has increased as well. Pesticides are used in urban settings to control weeds and insects on lawns, golf courses, cemeteries, and parks; to control insects in and around homes and commercial buildings; to clear vegetation from railroad, transmission-line, and roadway rights-of-way; and to control pests in private and public gardens. Insecticides also are used to control mosquito and other pest populations in urban and undeveloped areas for the protection of public health and for nuisance reduction (Barbash and Resek, 1996).

Nineteen pesticides were detected in two or more samples from the 72-well network (table 1; fig. 4). Of these 19 pesticides, 14 have established drinking-water regulations. Established drinking-water regulations are at least 2.9 times the maximum concentration reported for these pesticides, with the exception of dinoseb, an agricultural pesticide whose use was banned by the USEPA in 1987. Dinoseb concentrations in two samples exceeded established drinking-water regulations. Although no MCL has been established for dieldrin, the USEPA has classified it as a probable human carcinogen and has established a long-term health advisory of 2 µg/L. A long-term health advisory is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects following about 7 years of exposure, with a margin of safety (U.S. Environmental Protection Agency, 1996). One ground-water sample contained 5.6 µg/L of dieldrin and, thus, exceeded the long-term health advisory.

The most frequently detected pesticides in recently recharged ground water were atrazine, desethylatrazine (atrazine-degradation byproduct), simazine, metolachlor, prometon, and dieldrin (table 1; fig. 4). Atrazine and simazine were detected in about 40 to 70 percent of samples from urban

and agricultural land-use areas (fig. 5). Frequent detections in both urban and agricultural areas reflect the dual use of these pesticides--for agricultural weed control and for lawn maintenance and the clearing of vegetation along urban rights-of-way. Metolachlor was detected most frequently (about 75 percent), and in the highest concentrations, in agricultural areas (fig. 5), reflecting its primary use for agricultural weed control. Prometon and dieldrin were detected most frequently in urban areas, reflecting their primary use as nonagricultural pesticides.

Prometon is applied beneath asphalt and along roadways and other rights-of-way to control weed growth. Dieldrin was used primarily to control termite populations in residential areas before being banned by the USEPA in the 1980's. The frequent detection (about 25 percent) of dieldrin in shallow ground water underlying new urban areas 10 or more years after its use was banned demonstrates the persistence of this pesticide in ground water.

Table 1. Concentrations and detection frequencies of pesticides detected in two or more samples, Glassboro study area, New Jersey

[µg/L, micrograms per liter; --, not established; <, less than; NDV, nondetect value; E, estimated concentration; MCL, maximum contaminant level; LHA, lifetime health advisory]

Compound	Common name	NDV (µg/L)	Percentage of wells with detections	Median of detected concentrations (µg/L)	Maximum detected concentration (µg/L)	MCL or LHA (µg/L)
Herbicides						
Atrazine	AAtrex, Gesaprim	<0.001	50.0	0.005	0.676	¹ 3
Simazine	Aquazine, Princep, GESatop, Weedex	<.005	38.9	.045	1.38	¹ 4
Metolachlor	Dual, Pennant	<.002	34.7	.004	.466	² 70
Prometon	Gesagram, prometone	<.018	22.2	.066	4.83	² 100
Diuron	Karmex, Direx, DCMU	<.02	6.9	.06	2.0	² 10
Dinoseb	DNBP, DN 289, Premerge, Aretit, Ivosit, dinoseb	<.035	5.5	4.04	40.0	¹ 7
Terbacil	Sinbar	<.007	5.5	.026	.495	² 90
Alachlor	Lasso	<.002	4.2	.060	.09	¹ 2
Pendimethalin	Prowl, Stomp, Herbadox, pendimethaline	<.004	4.2	.011	.0279	--
Tebuthiuron	Spike, Perflan	<.01	4.2	.12	1.43	² 500
Bentazon	Basagran, bentazone	<.014	2.8	.115	.20	² 200
Metribuzin	Lexone, Sencor	<.004	2.8	.084	.159	² 100
Trifluralin	Treflan, Trilin, Elancolan, trifluraline	<.002	2.8	.008	.0136	² 5
Degradation Products						
Atrazine, desethyl-	Atrazine metabolite	<.002	48.6	.003	.48	--
Heptachlor epoxide	Heptachlor metabolite	<.01	5.5	.02	.07	--
DDE, p,p'-	p,p'-DDT metabolite	<.006	2.8	E.001	E.0018	--
Insecticides						
Dieldrin	Panoram D-31, Octalox, Compound 497	<.001	13.9	.02	5.6	--
Carbofuran	Furadan, Curaterr, Yaltox	<.003	6.9	.023	.0659	¹ 40
Carbaryl	Sevin, Savit	<.003	5.5	.018	.0313	² 700

¹MCL (U.S. Environmental Protection Agency, 1996)

²LHA (U.S. Environmental Protection Agency, 1996)

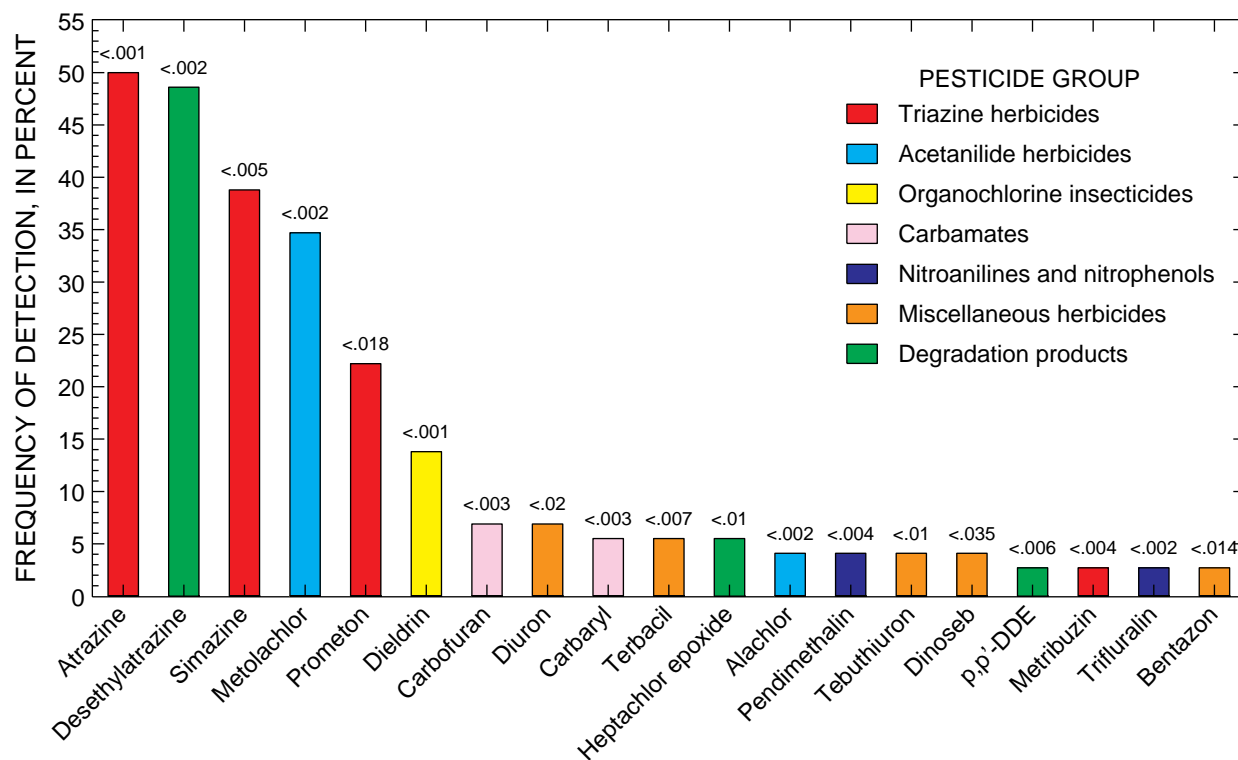


Figure 4. Detection frequencies of pesticides detected in two or more samples from 72-well network, Glassboro study area, New Jersey. (Values above bars indicate nondetect value, in micrograms per liter; <, less than)

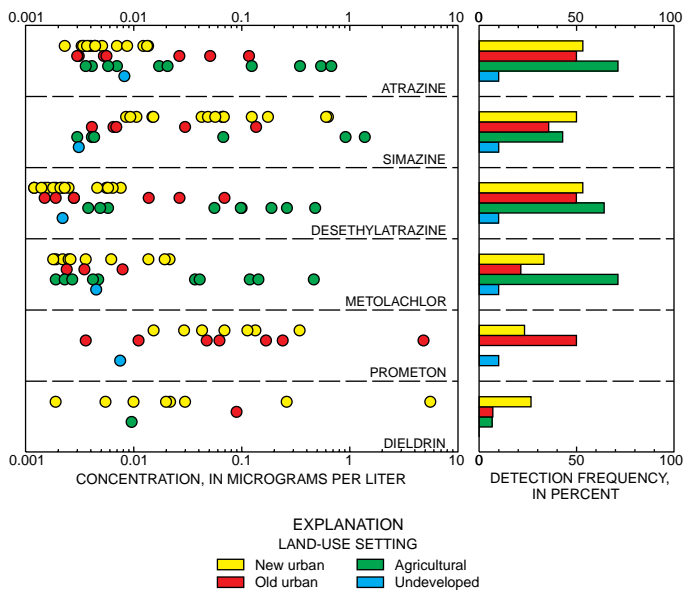


Figure 5. Detection frequencies and distribution of concentrations of most frequently detected pesticides by land-use setting, Glassboro study area, New Jersey.

VOLATILE ORGANIC COMPOUNDS IN RECENTLY RECHARGED GROUND WATER

VOC's are a class of organic compounds that have a multitude of uses in modern society. VOC's are present in fuels and the exhaust from their combustion. They are found in common household products, such as air fresheners, bathroom deodorants, cleaning and polishing products, paints, solvents, and adhesives. They are also widely used in industrial applications as solvent degreasers and refrigerants, in the dry-cleaning industry, in the manufacture of pharmaceutical products and plastics, and in agricultural applications as active and

inactive components of pesticides and fumigants (Bloemen and Burn, 1993; Smith and others, 1988; Verschuere, 1983).

Seventeen VOC's were detected in two or more samples from the 72-well network (table 2; fig. 6). Of these 17 VOC's, 13 either are regulated or have been assigned proposed or draft regulations by the USEPA and NJDEP. None of the samples contained VOC concentrations greater than an established drinking-water regulation; USEPA or NJDEP drinking-water regulations are at least 5 times the maximum concentration reported for these VOC's. One sample, however, contained methyl tert-butyl ether (MTBE) at a concentration of 43.8 µg/L. Although no drinking-water regulation has been established for MTBE, the USEPA has issued a draft lifetime health advisory of 20 to 200 µg/L (U.S. Environmental Protection Agency, 1996). A lifetime health advisory is the concentration of a chemical in drinking water that is not expected to cause any adverse carcinogenic effects over a lifetime of exposure, with a margin of safety (U.S. Environmental Protection Agency, 1996). The concentration of MTBE in this sample exceeded the lower limit of this draft advisory.

The most frequently detected VOC's were chloroform, MTBE, carbon disulfide, 1,1,1-trichloroethane, and tetrachloroethene (table 2; fig. 7). Detection frequencies and concentrations of these compounds generally were highest in the urban areas and lowest in the agricultural and undeveloped areas (fig. 7); however, most concentrations were low. The median detected concentration for each of these compounds was less than 1.0 µg/L, and the maximum concentration for three of these compounds was less than 1.0 µg/L (table 2). The maximum concentrations of chloroform and MTBE were 5.6 and 43.8 µg/L, respectively.

One plausible source of widespread low concentrations of certain VOC's in recently recharged ground water is rainfall. VOC's are defined as volatile because they evaporate readily. Once introduced into the atmosphere, VOC's are dispersed and

Table 2. Concentrations and detection frequencies of volatile organic compounds detected in two or more samples, Glassboro study area, New Jersey

[µg/L, micrograms per liter; --, not established; <, less than; NDV, nondetect value; E, estimated concentration; MCL, maximum contaminant level; LHA, lifetime health advisory]

Compound	Common name	NDV (µg/L)	Percentage of wells with detections	Median of detected concentrations (µg/L)	Maximum concentration (µg/L)	MCL or LHA (µg/L)
Trichloromethane	Chloroform	<0.05	80.5	0.06	5.6	⁵ 80-100
Methyl tert-butyl ether	MTBE	<.1	44.4	.20	43.8	⁵ 20-200
Carbon disulfide	Carbon disulfide	<.05	38.9	E.01	E.04	--
Methylchloroform	TCA, 1,1,1-Trichloroethane	<.05	27.7	E.025	.64	² 26
Perchloroethene	PCE, Tetrachloroethene	<.05	23.6	E.01	.17	² 1
Trichlorofluoromethane	CFC 11, Freon 11	<.1	11.1	.11	.48	³ 2,000
Iodomethane	Methyl iodide	<.05	8.3	E.015	.17	--
1,1-Dichloroethene	Vinylidene chloride	<.1	6.9	E.01	E.04	² 2
Methylbenzene	Toluene	<.05	6.9	E.02	.12	¹ 1,000
Bromodichloromethane	Dichlorobromomethane	<.1	5.5	E.02	E.05	⁴ 80-100
Trichloroethene	TCE	<.05	5.5	E.005	E.007	² 1
Tert-amyl methyl ether	TAME	<.1	4.2	E.01	E.02	--
1,2-Dichlorobenzene	o-Dichlorobenzene, 1,2-DCB	<.05	4.2	E.006	E.01	¹ 600
Dibromochloromethane	Dibromochloromethane	<.1	4.2	E.03	E.04	¹ 100
Ethylbenzene	Phenylethane	<.05	4.2	E.009	E.01	¹ 700
Dichlorodifluoromethane	CFC 12, Freon 12	<.2	4.2	.42	4.3	³ 1,000
1,3-Dimethylbenzene	m- and p-Xylene	<.05	4.2	E.01	E.02	--
1,4-Dimethylbenzene						

¹MCL (U.S. Environmental Protection Agency, 1996)

²NJDEP MCL (Shelton, 1994)

³LHA (U.S. Environmental Protection Agency, 1996)

⁴Proposed MCL (U.S. Environmental Protection Agency, 1996)

⁵Proposed LHA (U.S. Environmental Protection Agency, 1996)

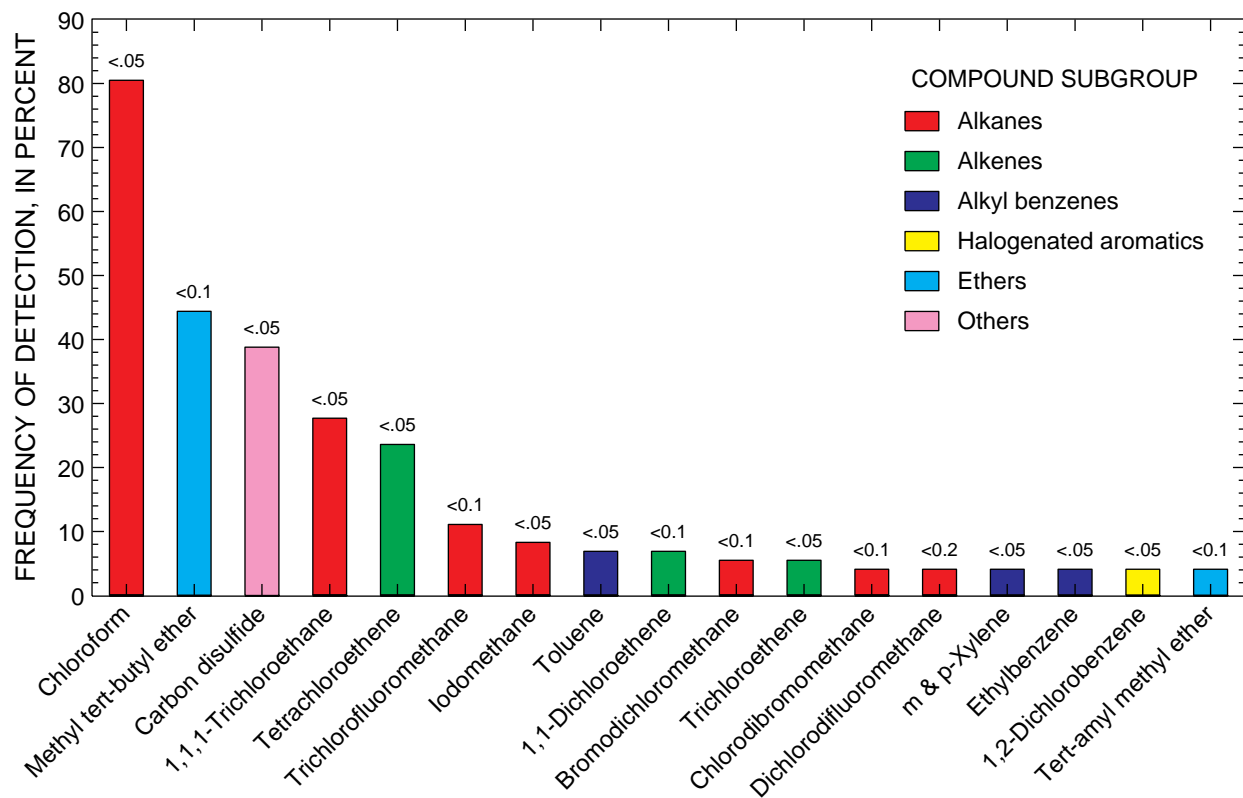


Figure 6. Detection frequencies of volatile organic compounds detected in two or more samples from 72-well network, Glassboro study area, New Jersey. (Values above bars indicate nondetect value, in micrograms per liter; <, less than)

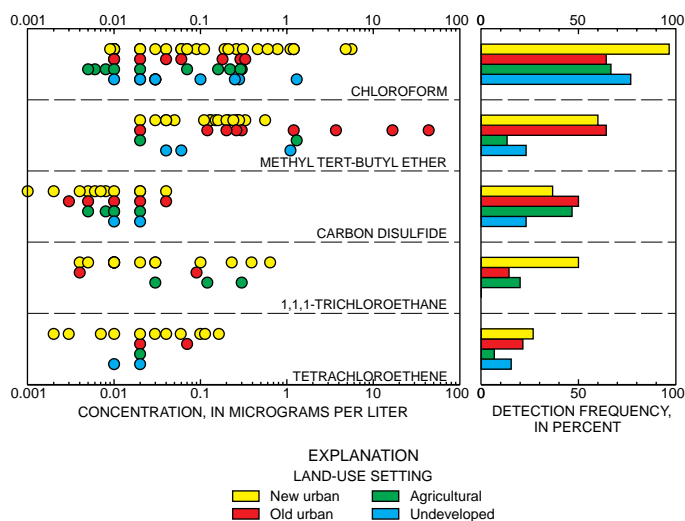


Figure 7. Detection frequencies and distribution of concentrations of most frequently detected volatile organic compounds by land-use setting, Glassboro study area, New Jersey.

diluted by wind. Some VOC's, such as MTBE, are highly soluble in water. These compounds can dissolve in precipitation which, upon percolating through the unsaturated zone, may introduce low concentrations of these water-soluble VOC's to ground water over a wide geographic area. The presence and concentrations of VOC's in the atmosphere, and the movement and fate of these compounds through the unsaturated and saturated zones in the Glassboro study area, are currently being evaluated (A.L. Baehr, U.S. Geological Survey, written commun., 1997). Results of this investigation may indicate

whether atmospheric deposition is a likely source of the widespread low concentrations of some water-soluble VOC's in recently recharged ground water.

Urban stormwater runoff is another likely source of certain VOC's in shallow ground water. From 1991 through 1995, USGS personnel collected 592 stormwater-runoff samples from 16 cities across the Nation. Some of the more frequently occurring VOC's in these samples include chloroform, tetrachloroethene, and MTBE (Delzer and others, 1996).

High detection frequencies and high concentrations of VOC's in the new and old urban areas relative to agricultural and undeveloped areas are likely the result of increased human activity and VOC use in urban settings. Chloroform, the most frequently detected VOC, is a common byproduct of the chlorination of public drinking-water supplies. During the process of chlorination, chlorine can react with naturally occurring humic substances to form chloroform in the treated water. Public-supply water can recharge the surficial aquifer system in urban settings through a variety of sources, including lawn sprinklers, swimming pools, leaking water or sewer lines, septic systems, and retention basins. MTBE, the second most frequently detected VOC, is commonly used as a fuel oxygenate to reduce the concentration of ozone and carbon monoxide in the atmosphere. The high detection frequency and high concentrations of MTBE in new and old urban settings are likely due, in part, to increased use of oxygenated gasoline and emissions from automobiles, urban stormwater runoff from roadways and parking lots, and leakage from underground storage tanks at gasoline stations and other commercial and industrial facilities (Squillace and others, 1995; Delzer and others, 1996).

IMPLICATIONS FOR PUBLIC AND DOMESTIC SUPPLY

In this study, nitrate (as nitrogen), pesticides, and VOC's were frequently detected in recently recharged (shallow) ground water beneath the Glassboro study area. Concentrations of nitrate were highest in agricultural areas, where they exceeded the USEPA MCL of 10 mg/L as nitrogen in 60 percent of samples. In contrast, the concentration in only one sample from the urban and undeveloped areas exceeded this regulation. Concentrations of pesticides and VOC's generally were low and rarely exceeded established USEPA and NJDEP drinking-water regulations. In fact, with the exception of dinoseb, established drinking-water regulations are at least 2.9 times the maximum concentration for pesticides and at least 5 times the maximum concentration for VOC's reported in water-quality samples from the 72-well network. The concentration of dinoseb, an agricultural pesticide whose use was banned by the USEPA in 1987, exceeded the drinking-water regulation in two samples.

Elevated nitrate concentrations and widespread low concentrations of pesticides and VOC's indicate that human activities have affected the chemical quality of shallow ground water underlying the Glassboro study area. But does the presence of these compounds at their reported concentrations have adverse implications for the use of this aquifer system as a source of public and domestic supply? The following issues need to be considered before this question can be answered definitively:

- This study focused only on the chemical quality of recently recharged ground water in the surficial aquifer system. Because this water is the youngest and most vulnerable to contamination, it is rarely, if ever, used for public or domestic supply. With time, however, this water will migrate deeper into the aquifer system and, in the absence of complete degradation or significant sorption and dispersion of any contaminants, could eventually affect the quality of water deeper in the system, the current source of public and domestic supply. The fate of selected chemicals, especially nitrate, as they move deeper into the aquifer system, and the likelihood that they will ultimately affect the quality of public and domestic supplies, are being examined as part of an ongoing investigation in the Glassboro study area (A.L. Baehr, written commun., 1997).

- Although established drinking-water regulations generally were not exceeded, many pesticides, VOC's, and their degradation byproducts have not been assigned drinking-water regulations by the USEPA or NJDEP. Existing regulations may be revised as knowledge of the toxicity of these compounds increases. Also, drinking-water regulations are currently based on the concentration of individual compounds and do not account for possible cumulative health effects of the presence of more than one compound in the same well (Barbash and Resek, 1996). The total number and cumulative concentration of all pesticides and VOC's in each sample are illustrated in figure 8. The total number of compounds ranged from 1 to 23 per sample; the total concentration ranged from 0.0047 to 43.8 $\mu\text{g/L}$. The presence of multiple pesticides and (or) VOC's, of course, increases the overall concentration of organic compounds in a given sample. The possibility that the presence of multiple organic compounds, even at low concentrations, may have a

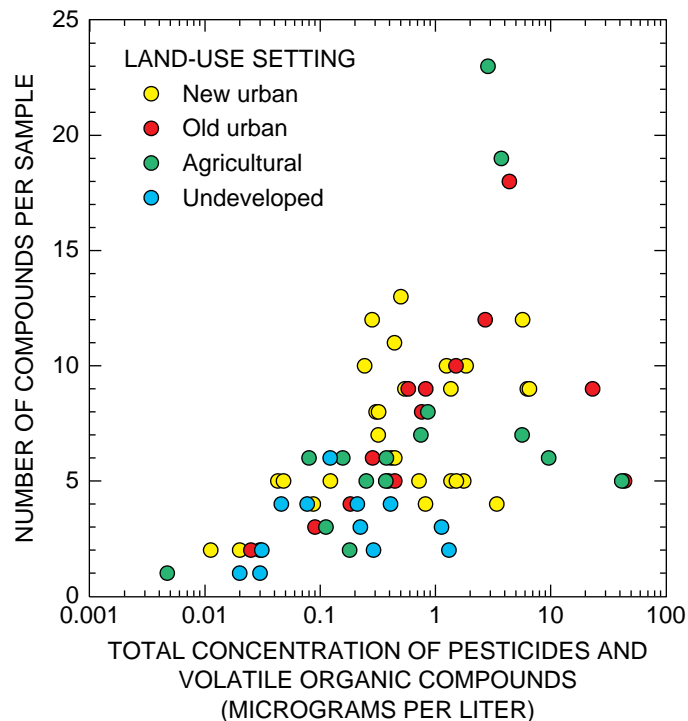


Figure 8. Total number and total concentration of organic compounds in samples from 72-well network, Glassboro study area, New Jersey.

synergistic adverse health consequence is an area of current research (Biradar and Rayburn, 1995; Marinovich and others, 1996).

- The concentration of some compounds, especially pesticides, in shallow ground water can fluctuate during the year as a result of seasonal patterns in their application (Barbash and Resek, 1996). Because ground-water samples were collected during September-December for this study, they may not reflect maximum concentrations associated with springtime applications of pesticides.

- This study documents the presence and concentrations of only a limited number of pesticide-degradation byproducts. Because many pesticides are unstable in soil and the unsaturated zone, they degrade to other compounds that can be equally harmful to human health. Results of previous investigations indicate that degradation products account for most of the pesticide load in shallow ground water (Kolpin and others, 1995; 1996). In fact, desethylatrazine, a degradation byproduct of the pesticide atrazine, was the second most frequently detected pesticide compound in this study. Further investigation is needed to document the presence and concentration of pesticide-degradation byproducts in recently recharged ground water before the full effect of pesticide use in the Glassboro study area can be known.

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